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Analyzing stakeholder's perceptions of uncertainty to advance collaborative sustainability science: Case study of the watershed assessment of nutrient loads to the Detroit River project

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ABSTRACT

The topic of uncertainty is of growing interest in the impact assessment (IA) field, due to increases in contextual uncertainty and the awareness of the complexity of advanced analysis. IA practitioners can now draw on maturing theoretical frameworks to manage uncertainty, but questions remain about whether these frameworks align with stakeholder concerns and how their use can benefit IA projects. This article reports on an empirical application of the leading framework for organizing IA uncertainty proposed by Walker et al. in 2003. Twenty-two stakeholders involved in a large water quality modeling project in the U.S. Great Lakes region were interviewed, and their uncertainty-related statements were categorized according to the Walker dimensions. Overall, the framework's three primary dimensions performed well and allowed for the analysis of differences in uncertainty perceptions among the stakeholder groups. In addition, the analysis resulted in useful insights for the project, such as identifying top scenario uncertainties to use for modeling as well as highlighting specific concerns about the assumptions, data, and modeling approach for further exploration. In addition to encompassing the variety of uncertainty concerns raised in the case, the paper illustrates how the Walker framework can support IA practices like stakeholder collaboration and scenario construction which may improve IA outcomes.

1. Introduction

Impact assessment (IA) practitioners have become increasingly aware of the importance of thoughtfully and transparently addressing the uncertainty of their analyses. De Jongh (1988) observed that IA uncertainties arise not only from the prediction methods themselves (often computer models), but also from the choices involved in the IA approach, including the methods used, the types of impacts included, and the policy alternatives considered. The topic is now a major focus of the IA field; a recent review identified over 134 papers on the topic, with 75% published since 2005 (Leung et al., 2015). Several major trends may explain this growing focus. Environmental, economic, and social systems have become less predictable, and long-run analyses must address issues such as climate change and emerging technologies. Additionally, the growing concern with uncertainty reflects the long-term societal trends described by Funtowicz and Ravetz (1994), who proposed the term *post-normal science* for situations that combined high uncertainty, high-stakes decisions, and deeply intertwined facts and values. A heightened awareness of the limitations of technical analysis by stakeholders and the increasing diversity of values has led to greater collaboration in IA, defined as the inclusion of diverse stakeholders at each step of the IA process. The growing concern with uncertainty, and increasing collaboration in IA, have led to shifts in both IA scholarship and practice.

Since Funtowicz and Ravetz (1994), subsequent theoretical articles have elaborated the many potential forms of uncertainty in IA, providing guidance for how they might be analyzed within IA projects. These transdisciplinary frameworks seek to provide enough detail to be constructive, yet provide the wide scope needed to be inclusive of diverse perspectives. Ascough et al.'s (2008) review identifies nine uncertainty frameworks that have been proposed since 1990. Among these, the uncertainty framework proposed by Walker et al. (2003) has emerged as a widely cited synthesis of the multiple dimensions of the concept (e.g., it has been applied to water modeling in Refsgaard et al., 2007). Walker et al.'s framework examines the *location*, *level*, and *nature* of uncertainties in model-based decision-support contexts. This paper draws on the Walker et al. framework, and the following section presents it in more detail and discusses its existing critiques. These theoretical developments have been accompanied by related changes to professional practices that seek to improve the analysis and

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communication of IA uncertainty.

The categories within the Walker et al. framework includes one for scenario uncertainties, reflecting the growing interest in the use of scenarios to structure IA analyses (Duinker and Greig, 2007; Zhu et al., 2011). A *scenario*, a plausible description of a future state of a system and a discussion of the driving forces that may result in such a future, has become more popular for environmental analyses that seek to incorporate uncertainties such as climate change (Cobb and Thompson, 2012; Mahmoud et al., 2009; Peterson et al., 2003; Sierra et al., 2017; Volkery and Ribeiro, 2009). Scenario planning methodologies aim to incorporate uncertainty into the logic of project analysis, but do so by identifying a limited set of scenario uncertainties that are used to construct multiple plausible futures. The number of uncertainties and the conceptualizations of uncertainty vary among scenario methods. The widely used qualitative Global Business Network method identifies a small number of qualitative "driving force" uncertainties to construct scenarios (Van der Heijden, 1996). Other schools of thought advocate the analysis of multiple scenarios defined by possible values among quantitative variables (Lempert et al., 2003).

Zhu et al. provide a case study of how scenario analysis can be used to conduct an environmental assessment (Zhu et al., 2011). In contrast with the typical trend extrapolation method where a model is used to create a single prediction of the future, they propose a scenario process where uncertainties are identified which then inform alternative assumptions and inputs to a model to create multiple scenarios. In the cases provided of assessment projects in China, these uncertainties include the degree of economic growth, the amount of environmental protection by local governments, or the extent of future water re-use within different study areas. Although they acknowledge stakeholder consultation is an essential part of scenario planning, only one of their cases featured consultation conducted after draft scenarios were created. The idea explored by this paper is that the application of the Walker et al. framework to organize uncertainties can produce valuable insights, which include identifying scenario uncertainties that can be used to create analysis scenarios.

Another change in professional practice has been a growing interest in how uncertainties can best be communicated to stakeholders. This includes issues such as conveying the strength of the scientific evidence on a particular topic, the statistical uncertainty corresponding with different estimates, or the range of values possible under different future scenarios. Unique among the proposed uncertainty typologies, Walker et al.'s has been formally incorporated into IA practices and adopted by the Netherlands Environmental Assessment Agency as part of its tools and practices for analyzing and communicating IA uncertainties (described in Jeroen et al., 2008, Petersen et al., 2011). One such document is the guidance for "Uncertainty Assessment and Communication," which catalogues representational strategies for conveying different forms of uncertainty (Petersen et al., 2013). Similarly, the report of the US National Academies' Committee on Environmental Decision Making Under Uncertainty (Institute of Medicine. 2013) argues that such communications should be sensitive to the needs of different stakeholders, but it provides limited advice on how to accomplish this in practice. Leung et al.'s (2015) review of uncertainty research in impact assessment specifically identifies communication as an area where further research is needed. Others have critiqued the focus on communication, arguing instead for addressing uncertainty through participation or deliberation, but theoretical frameworks are still useful for organizing such discussions (Bond et al., 2015; Cardenas and Halman, 2016; Duncan, 2013; Newig et al., 2005).

However, the practical usefulness of an uncertainty framework for informing communication efforts depends in part on how well it aligns with diverse stakeholders' understandings of uncertainty. For example, the central three dimensions of the Walker et al. framework were derived through a process of "consultation and discussion" among experts, not from direct empirical evidence (Walker et al., 2003, p. 8). Krayer von Krauss and Janssen (2005) argue that the framework's ideas were "relatively unfamiliar—and perhaps somewhat controversial" to experts and advocate introducing them through a careful interview protocol that indirectly introduces the concepts.

Therefore this paper has both theoretical and practice-oriented motivations. Theoretically, given the growing focus on the Walker et al. framework as an analytic tool for research and a prescriptive tool shaping practice, there is a need to more rigorously assess its utility for analyzing stakeholder concerns. This is especially important since it was developed through consultation with IA experts, not stakeholders. From the perspective of practice, the paper explores the value of applying the Walker et al. framework to organize the diffuse collection of concerns collected from stakeholders, to see whether it can generate useful inputs to shape the project. Among these, some of the most important are identifying scenario uncertainties, but they also include identifying issues and concerns for further consideration. Ultimately, doing so may improve the usefulness and legitimacy of the project results.

To address these two motivations, the paper reports on an empirical application of the Walker et al. framework to analyze interviews conducted among a diverse stakeholder group participating in a complex IA project. An analysis explores the prevalence of concerns falling into the framework's categories, as well as investigates whether there is a relationship between uncertainty perceptions and stakeholder categories. It also documents how close analysis of two uncertainty categories resulted in useful project inputs, and discusses some of the broader ways this type of investigation benefited the project. The context of this research is a multi-year water quality modeling project (planned for January 2016 to December 2018), which at this writing is not yet complete. Therefore, its scope is limited to findings derived from interviews conducted at the project launch, and discussion of how the results have been used thus far. A future paper will report on additional uncertainty-related issues after the project is completed.

The paper is organized as follows. First, a background section presents the Walker et al. framework, and discusses related theoretical critiques and empirical applications. The methods section introduces the case study and qualitative data collection and analysis approaches. The results presents the analysis of codes and specific uncertainties, and the discussion and conclusion comment on the theoretical and practical significance of the findings.

2. Background

This section introduces the Walker et al. uncertainty matrix, provides a brief overview its critiques and empirical applications, and introduces the specific research questions.

2.1. Walker's uncertainty matrix

After its initial appearance, the Walker et al. (2003) uncertainty matrix was re-published in somewhat revised form in Petersen et al. (2013). The latter version, shown in Fig. 1, was used for this study since it was taken to reflect this group's latest thinking. It also incorporates two additional dimensions intended to be useful in practical applications, specifically the *qualification of the knowledge base* and the *value-ladenness of choices*. This section briefly reviews its dimensions.

2.1.1. Location

The first dimension, *location* of uncertainty, is where the uncertainty exists within the whole model system. The location of uncertainty is defined by *context*, *data*, *model*, or *model outputs*.

- *Context* uncertainty is defined by Walker et al. (2003), p. 9) as the "conditions and circumstances … that underlie the choice of the boundaries of the system, and the framing of the issues and formulation of the problems to be addressed." This includes assumptions about the natural, technological, economic, social and political